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Motional characteristics of ultrasonic motor using Λ (lambda)-shaped stator

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Abstract

In this study, characteristics of novel ultrasonic motor with lambda shaped stator were investigated. A thin metal plate was used as a Λ(lambda)-shaped stator and four ceramic plate were attached on upper and bottom surface of the metal plate. From the stator, elliptical displacements of the contact line were obtained. When two sinusoidal sources with phase difference of 90° were applied to the ceramics, the symmetric and anti-symmetric displacements were combined at the contact line of the stator to make the elliptical motion. A finite element analysis (ATILA) was used for simulating the motional pattern of contact line of the stator. Stator characteristics depending on changes of ceramic size and thickness of metal were analyzed. The motor was fabricated by using results of FEA. Characteristics of the motor such as frequency, speed, torque, and pre-load were measured by using the driving system and measurement equipment.

Keywords: E. Actuators; Ultrasonic motor; FEM; ATILA

1. Introduction

Ultrasonic motors are of great interest due to the flexibility of miniaturization in comparison with conventional electromagnetic motors. Especially in information systems and medical industry, compact size of these motors makes them find wider applications. Ultrasonic motor have absence of magnetic interference, and high torque at low speed in compact size. So, its advantage in the application of medical, automation, robotics, aerospace and various other fields. Many different types of ultrasonic motors have been proposed up to date [1–4]. The stator of an ultrasonic motor that is activated by piezoelectric elements in ultrasonic frequency range develops different kinds of vibrations depending on its structure. Two different ways are generally available to control the friction along the stator–rotor contact interface, travelling-wave vibration and standing-wave vibration [5–9]. In this paper, we propose a Λ (lambda)-type ultrasonic motor using standing-wave that is easy to make. This motor has a lambda shaped stator, and can be easily fabricated because the stator has thin elastic body. Compared with previous ultrasonic motors, this motor has a simple structure and small size, and can reduce production time and find application in the small actuator industry. For determining the design parameters of the proposed motor, driving characteristics depending on ceramic length, thickness, and elastic body thickness were analyzed using FEM program (ATILA). Displacement characteristics depending on the resonance frequency and impedance were analyzed through FEM analysis, and then model of maximum displacement was chosen and fabricated. Characteristics of speed and torque about changes of pre-load, voltage and frequency were measured by using the fabricated ultrasonic motor.

2. Λ (lambda)-type ultrasonic motor

The stator consisted of a thin elastic body, and four piezoelectric ceramics polarized in thickness direction were attached on both sides of the body as in Fig. 1. When two harmonic voltages which had 90° phase difference were applied to the ceramics, the symmetric and anti-symmetric

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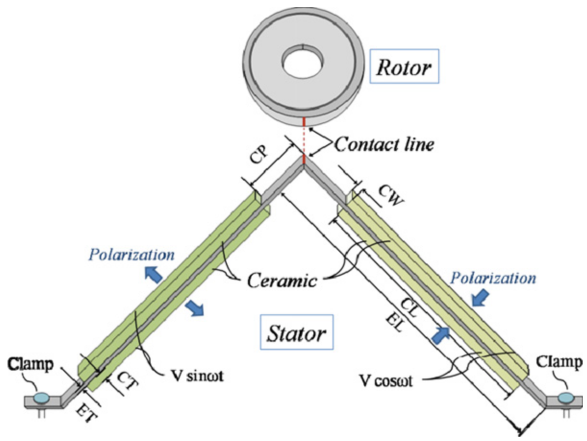

CL	Ceramic Length	EL	Elastic body Length
CW	Ceramic Width	ET	Elastic body Thickness
CT	Ceramic Thickness	CP	Ceramic Position

Fig. 1. Structure of lambda-type ultrasonic motor.

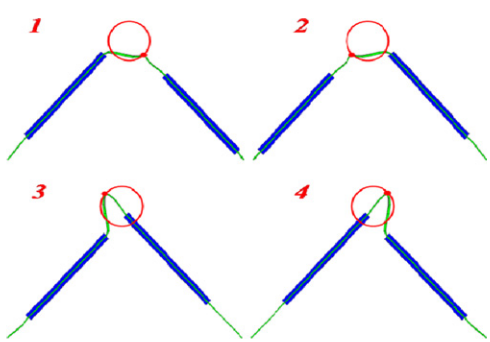

Fig. 2. Schematic diagram of elliptical motions of contact line for one cycle.

displacements were generated at the contact line to make the elliptical motion. The elliptical displacements were generated at the contact line. The elliptical displacement of a bimorph can be inferred by thin beam theory of mechanical vibration. In case of vibration mode of one side, the bimorph is horizontally expanded because two ceramics attached on both sides of the elastic body offsets each bending vibration mode.

Fig. 2 shows generating principle of the elliptical displacement at the contact line for one cycle. Motion of stator was represented in detail by using FEM program. Elliptical displacements were generated at the contact line for one cycle of 1 to 4 in Fig. 2. Rotation direction of rotor was determined through motion of contact line. The inverse motion could be realized by applying inverse phase of the applied voltage to the stator.

3. FEM simulations

The finite element analysis program (ATILA) was used to analyze the driving characteristics for changed size of the elastic body and ceramics. First modal analysis was conducted to determine the longitudinal vibration mode required for operating the motor. The vibration shapes of each mode were verified through modal analysis [10]. Frequencies representing the longitudinal vibration mode were analyzed by harmonic analysis. In a harmonic analysis, length of the ceramic, thickness of the ceramic, and thickness of the elastic body were analyzed for selecting the maximum displacement model. Table 1 shows size of simulated models.

Table 1
Variables for harmonic analysis.

Variables	Size (mm)
CL (ceramic length)	20–21–22–23–24–25–26
CT (ceramic thickness)	0.1–0.2–0.3–0.4–0.5–0.6–0.7
ET (elastic body thickness)	0.1–0.2–0.3–0.4–0.5

Material of the elastic body was steel, and PZT was used for the ceramics. Both ends of the stator were clamped. First, the influence of ceramic length was analyzed. The influence of ceramic thickness was analyzed. Because, the vibration mode of the lambda type ultrasonic motor is sensitive to ceramic length. At this case, width of the ceramic was fixed to 5 (mm). After determining the length, the ceramic thickness and elastic body were analyzed. The motor is susceptible to the change of length of ceramic, in order to obtain the exact mode it was analyzed as in Figs. 3 and 4. In this case, the ceramic width-5 (mm), ceramic thickness-0.2 (mm), elastic body thickness-0.2 (mm) were fixed. Two voltages of 10 (Vrms) which have 90 degree phase difference were applied to the ceramics. Fig. 3 shows the displacements depending on ceramic length and the maximum displacement was obtained from CL24. According to the vibration theory for the longitudinal vibration mode of ceramics, the displacement magnitude is proportional to the length. However, the displacement at the contact line will decrease due to the bucking phenomenon when the motor length is too long.

After fixing the length at 24 (mm), the maximum displacement was obtained at the 0.5 (mm) as in Fig. 4. When the thickness of elastic body was changed maximum displacement was verified at the thickness of 0.2 (mm) as in Fig. 5. The resonance frequency was inversely proportional to the ceramic length. In addition, the resonance frequency was proportional to the thickness of elastic body. In analyzed results, maximum elliptical displacement was obtained at 'ceramic length 24 (mm), ceramic thickness 0.5 (mm), ceramic width 5 (mm), elastic body thickness 0.2 (mm)′ (CL19CT0.5CW5ET0.2). Resonance mode for model of maximum elliptical displacement according to changes in frequency shown in Fig. 6, and the resonance frequency was represented at 28 (kHz). As analyzed results, maximum elliptical displacement was obtained at point of resonance in minimum impedance. Elliptical displacement affected speed and torque of the ultrasonic motor, the results would be mentioned through experiments.

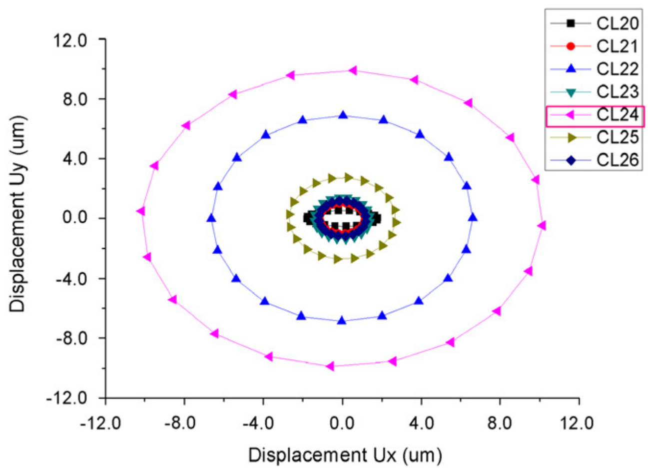

Fig. 3. Characteristic of elliptical displacement depending on the ceramic length.

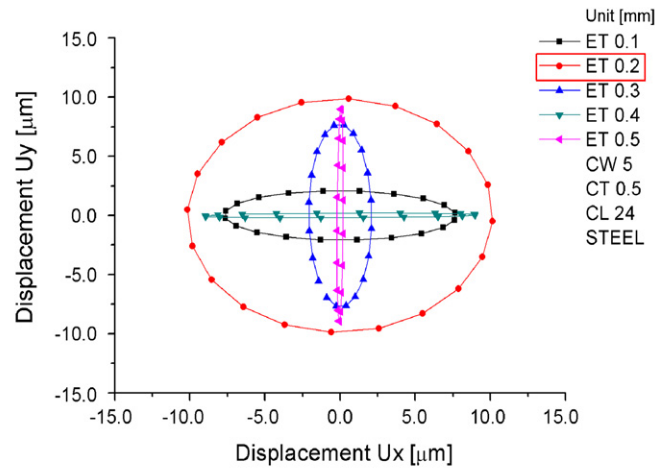

Fig. 5. Characteristic of elliptical displacement depending on the thickness of elastic body.

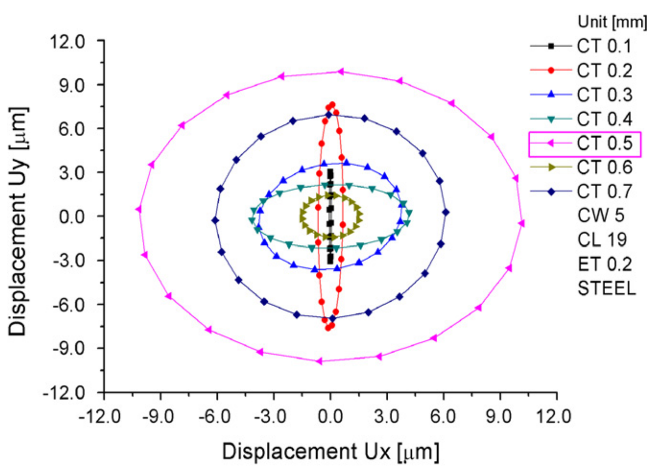

Fig. 4. Characteristic of elliptical displacement depending on the ceramic thickness.

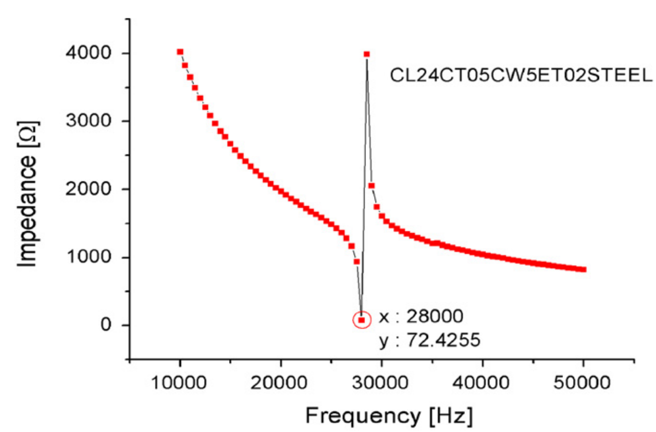

Fig. 6. Impedance curve of the optimized model (CL24CT05CW5ET02-STEEL).

4. Experiments

Fig. 7 shows a fabricated lambda type ultrasonic motor. Model 'CL24CT0.5CW5ET0.2', which had the maximum elliptical displacement was fabricated. The elastic body was fabricated to be a lambda shape. Also, four ceramics were prepared to have same width at the same size. The ceramics were attached to the elastic body using epoxy glue.

The experiment stage was set up as shown in Fig. 8. The rotor was connected to a push–pull gauge for applying pre-load by moving the gauge up and down. The stator was fixed at bottom side to contact of the rotor with the rotor. The speed of the motor was measured using a non-contact speed meter, and the torque of the motor was measured using a torque gauge. Also, push–pull gauge was used to control the preload to the rotor. The speeds of the motor depending on the frequency are shown in Fig. 9. The maximum speed was obtained at the resonance frequency. Speed was increased somewhat linearly below the resonance frequency and decrease sharply above the resonance frequency. It was found that the driving frequency was 27.8 (kHz).

Fig. 10 shows the characteristics of speed and torque of the motor depending on applied voltages at the resonance frequency. As results, the speeds and torque were increased by increasing the applied voltage from 5 (Vrms) to 20 (Vrms) at driving frequency of 27.8 (kHz). The lambda type ultrasonic motor has characteristics of high speed and high torque at the same time, because of the direct contact. Relatively, the low torque was measured in the low power. As same in the finite element analysis results, increasing voltages effected to the increased displacement and speed of the motor. Fig. 11 shows the speed and torque depending on the pre-load; the speed was inversely proportional to the pre-load. But the torque was proportional to the pre-load.

5. Conclusion

In this paper, newly designed lambda type ultrasonic motor was proposed. A finite element analysis program (ATILA) was used to simulate the driving characteristics and the elliptical displacement at the contact line. Vibration modes of the stator were determined by the modal

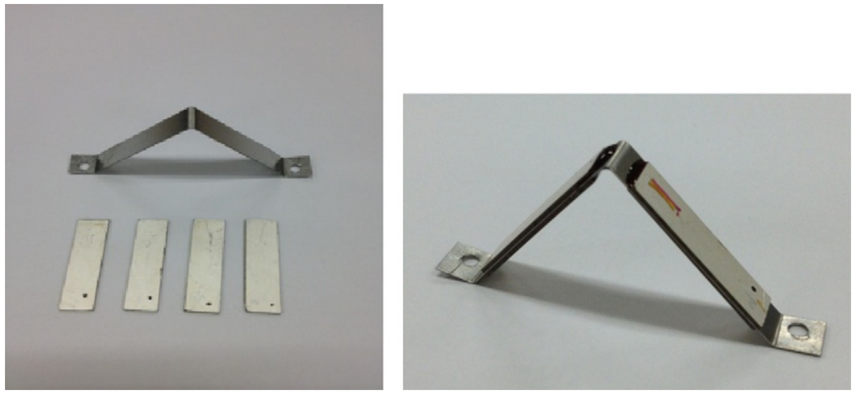

Fig. 7. Fabricated stator (ceramic and elastic body).

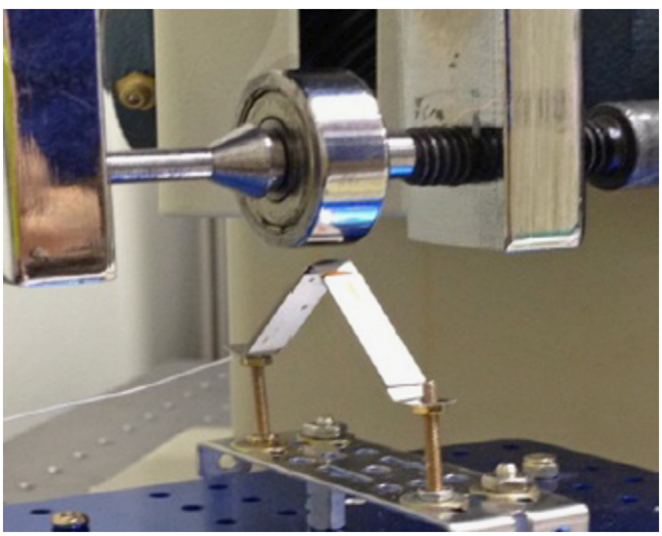

Fig. 8. Experimental setup of the lambda type ultrasonic motor (stator and rotor).

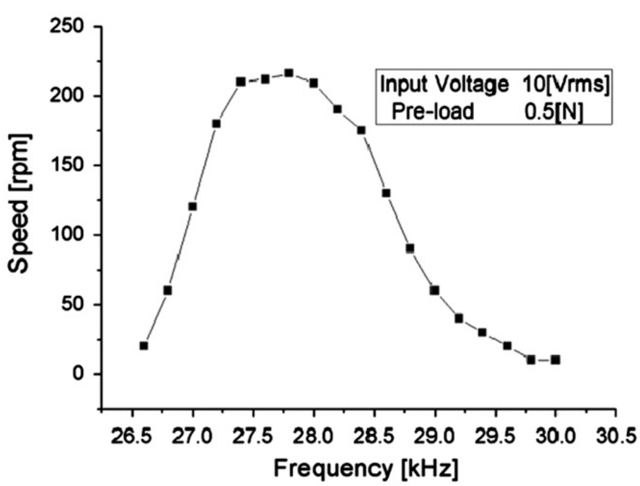

Fig. 9. Characteristic of speed depending on the frequency.

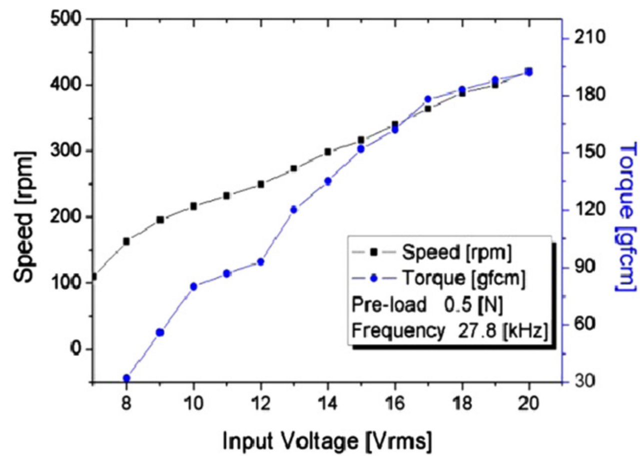

Fig. 10. Characteristic of speed and torque depending on the input voltage.

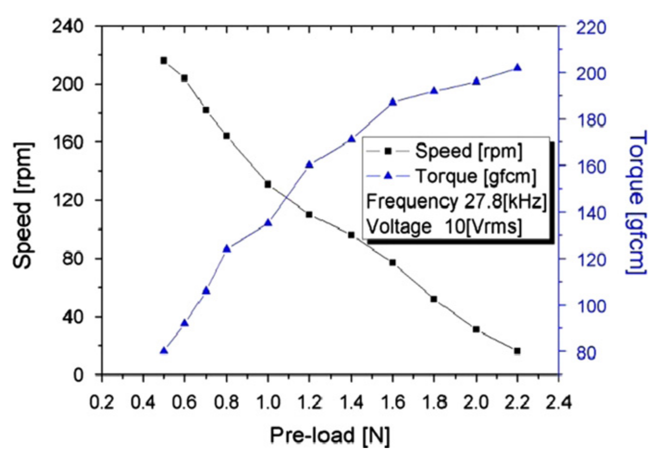

Fig. 11. Characteristic of speed and torque depending on the pre-load.

analysis of finite element analysis and displacement characteristics were defined through the harmonic analysis. As an analysis result, the maximum elliptical displacement was shown by 'CL24CT0.5CW5ET0.2'. Compared with the analysis results, increasing input voltages indicated increased elliptical displacement and speed of the motor. The maximum displacement of the contact line was generated at the resonant frequency. Also, the maximum speed was obtained at the resonance frequency. For a long-time stable driving, it is necessary to apply the pre-load including spring and to consider preventing abrasion due to friction between the rotor and stator. Existing ultrasonic motors that consist of complex structures can be replaced with a lambda type ultrasonic motor that can be fabricated more economically due to its simple structure.

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